Goup Project Descriptions

Ken Chen (ASIAA), Kuo-Chuan Pan (NTHUIoA), & Meng-Ru Wu (ASIoP)

Numerical Astrophysics Summer School: Astrophysical Fluid Dynamics
NTHU, Hsinchu, Taiwan, Sept 04–06, 2019

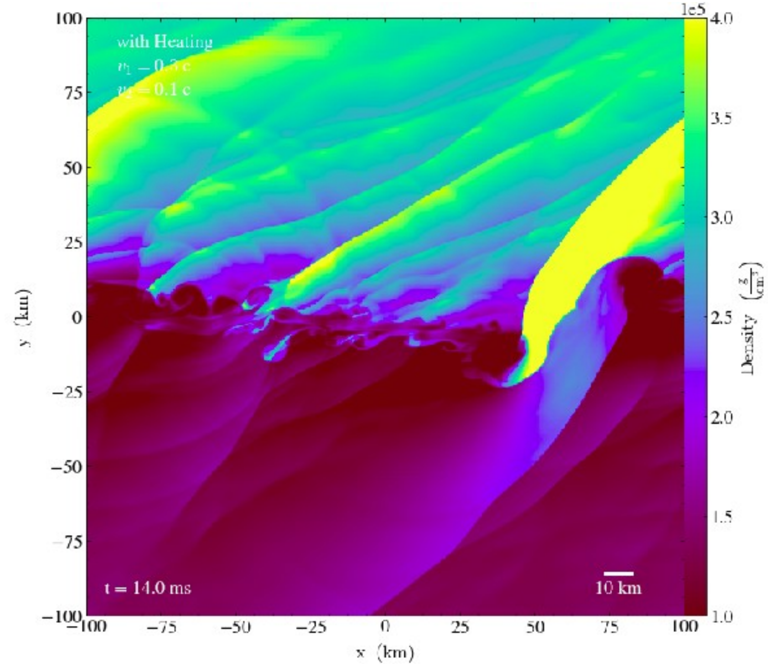
国立清華大學
NATIONAL TSING HUA UNIVERSITY
NCTS
PRPC
PHYSICS RESEARCH PROMOTION CENTER

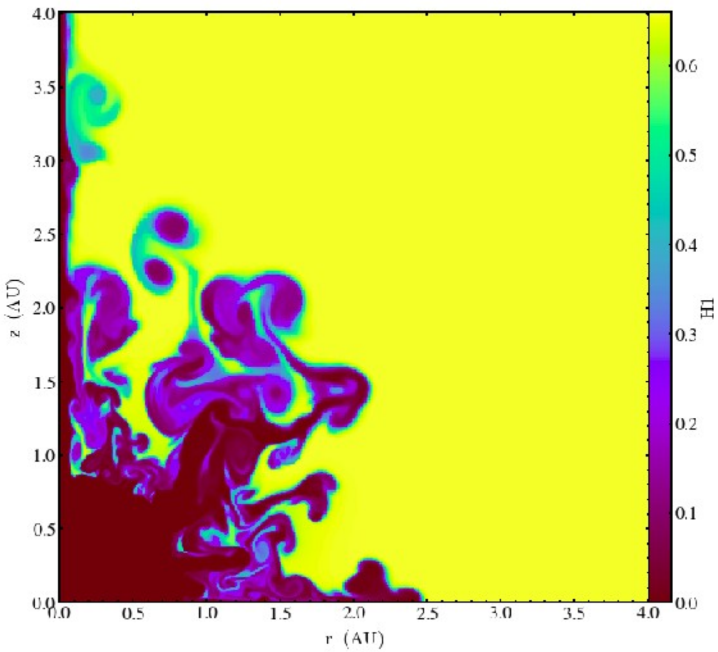
Three main projects

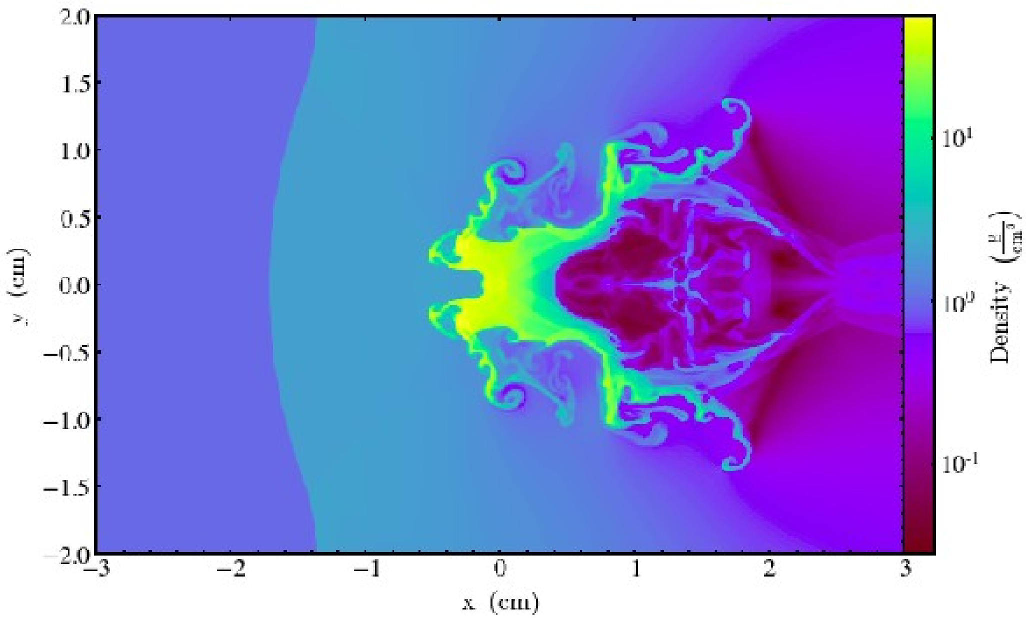
A: Mixing in neutron star merger ejecta

B: Shock Cloud Interaction

C: Exploding a star with a thermal bomb







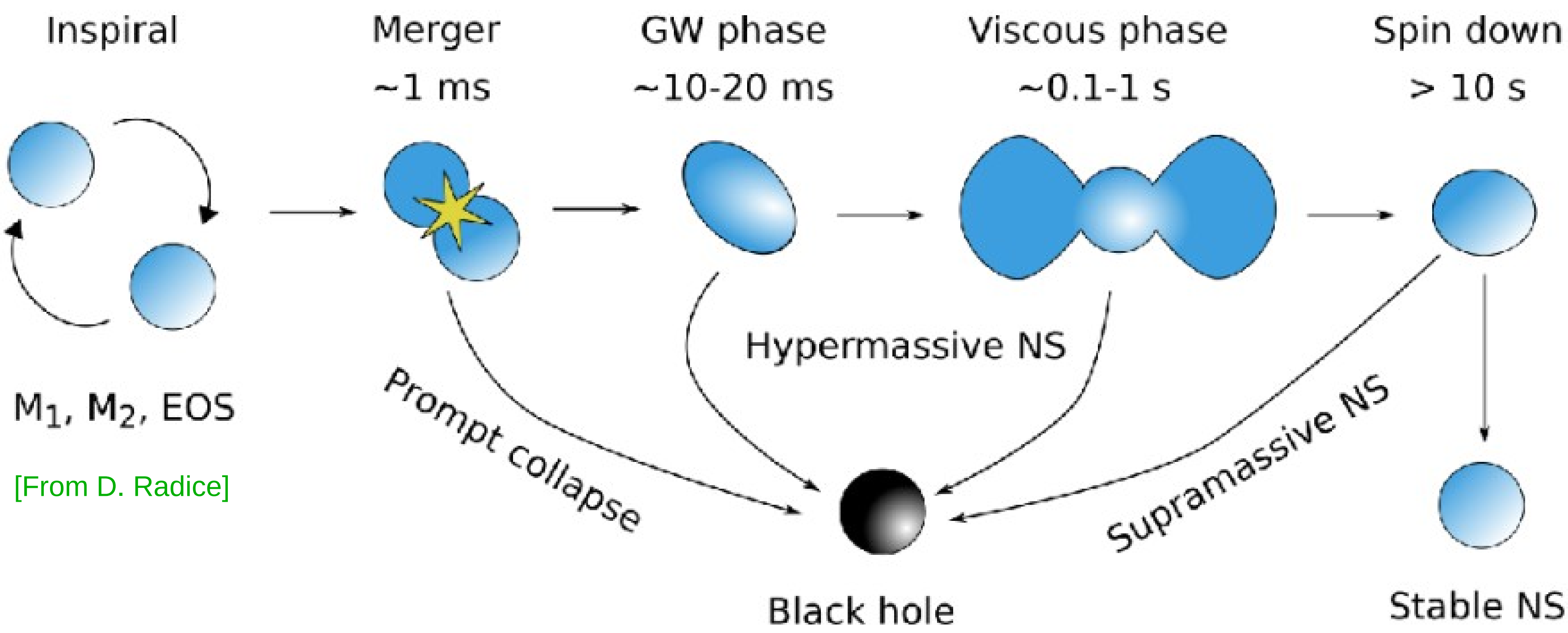
Project A: Mixing in neutron star merger ejecta

Project A: Mixing in neutron star merger ejecta

Mergers of two neutron stars can result in a variety of outcomes, depending on the initial state of the system and the yet-unknown nuclear EoS

$\rightarrow$ different post-merger GW signals & EM emissions

both were detected in GW170817!



[From D. Radice]

Project A: Mixing in neutron star merger ejecta

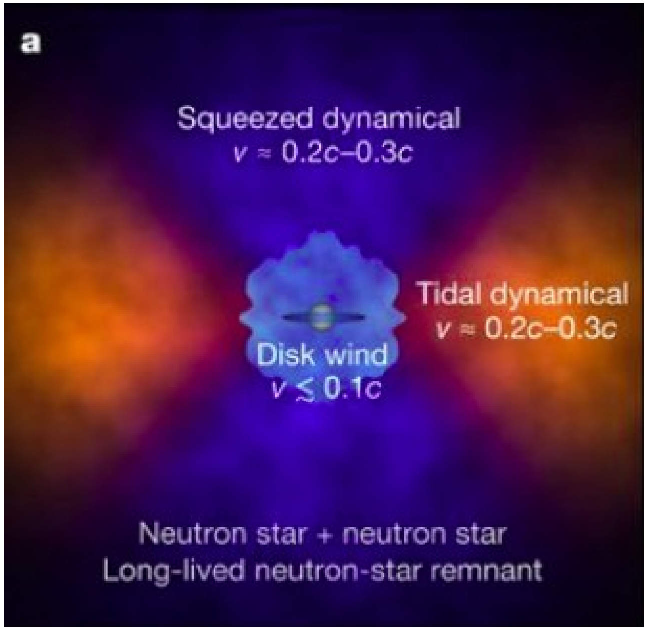
Different outflow components:

[Modified from Fujibayashi+ 2017]

Type of ejecta	Mass ($M_\odot$)	V_{ej}/c
Dynamical ejecta	$O(10^{-3})$	~ 0.2
Early viscosity-driven ejecta	$\sim 10^{-2}(\alpha_{vis}/0.02)$	$\sim 0.15 - 0.2$
Late-time viscosity-driven ejecta (polar)	$\sim 10^{-3}(t_\nu/s)$	~ 0.15
Late-time viscosity-driven ejecta (equatorial)	$\gtrsim 10^{-2}$	~ 0.05

Y_e	Direction	Duration
0.05–0.5	$\theta \gtrsim 20°$	$t - t_{merge} \lesssim 10\,\mathrm{ms}$
0.2–0.5	$\theta \gtrsim 30°$	$t - t_{merge} \lesssim 0.1\,\mathrm{s}$
0.4–0.5[a]	$\theta \lesssim 30°$	$t - t_{merge} \sim t_\nu \sim 10\,\mathrm{s}$
0.2–0.4[a]	$\theta \gtrsim 30°$	$t - t_{merge} \sim 1–10\,\mathrm{s}$

[Kasen+ 2017]

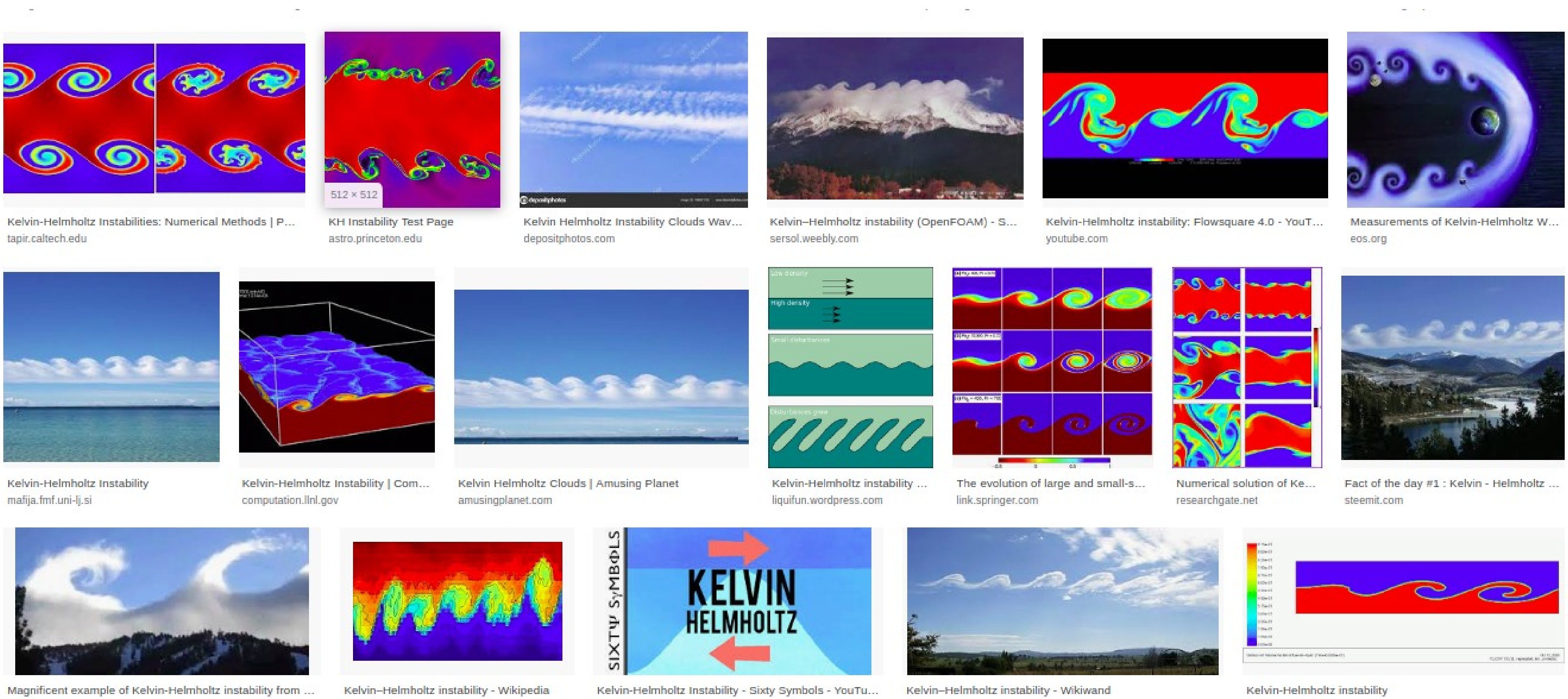


Y_e and v_{ej} can depend on the outflow drection

$(Y_e = n_e/n_b)$

Project A: Mixing in neutron star merger ejecta

Velocity shear drives instability at the interface of two fluids, which then generates fluid mixing → Kevin-Helmholtz instability



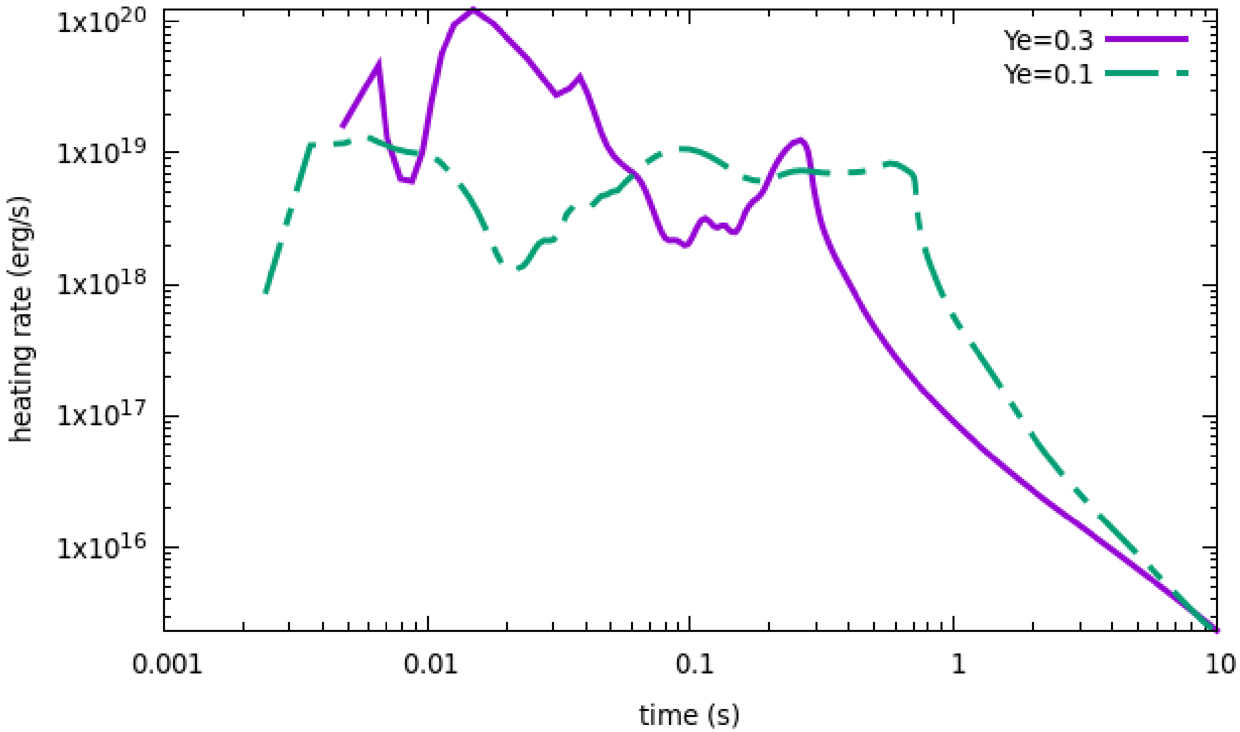
Project A: Mixing in neutron star merger ejecta

Merger ejecta not only simply expand and cool, but also receive energy inputs due to the decay of unstable heavy r-process nuclei (how the gold was made)

$\rightarrow$ composition-dependent nuclear heating

high Y_e: stronger earlier heating but last for a shorter time

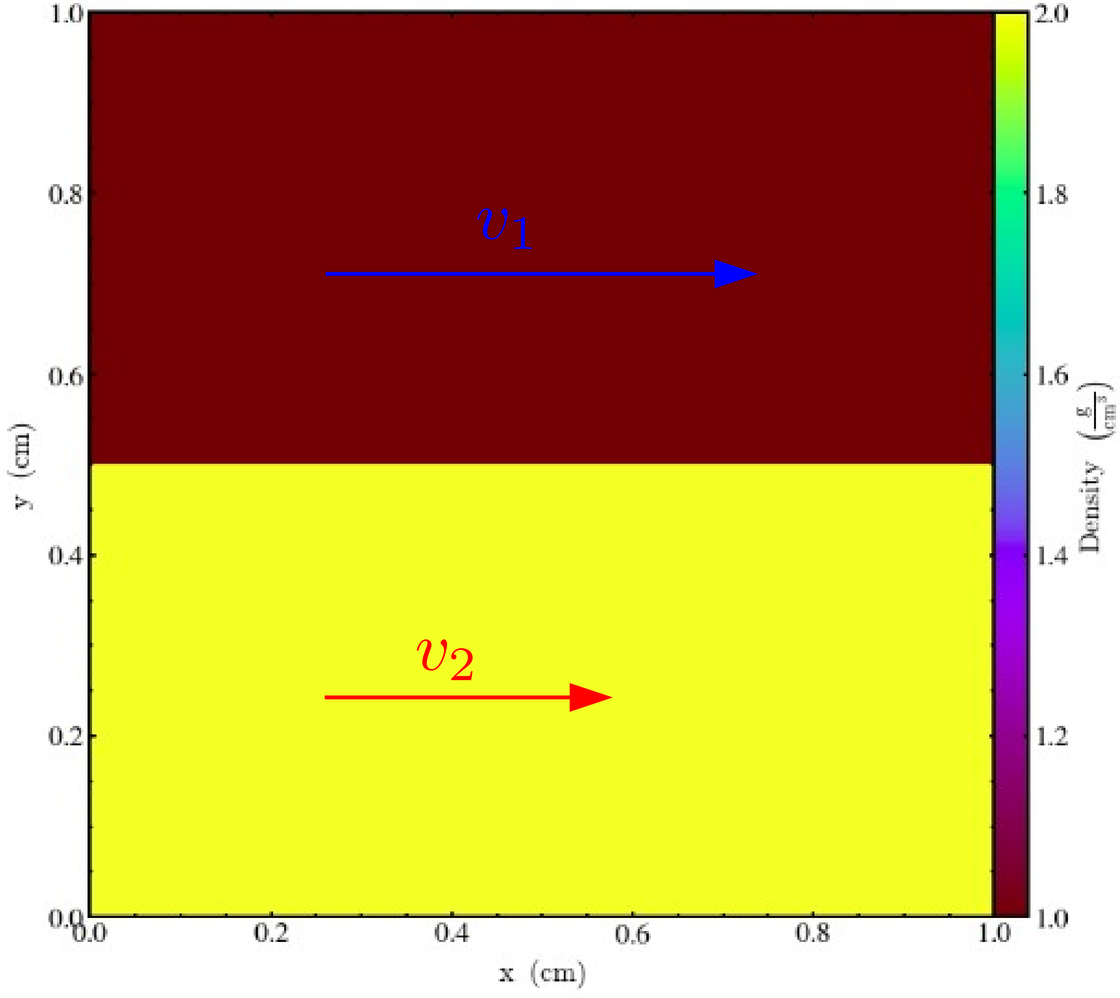
low Y_e: weaker earlier heating but last for a longer time



Does this affect the mixing?

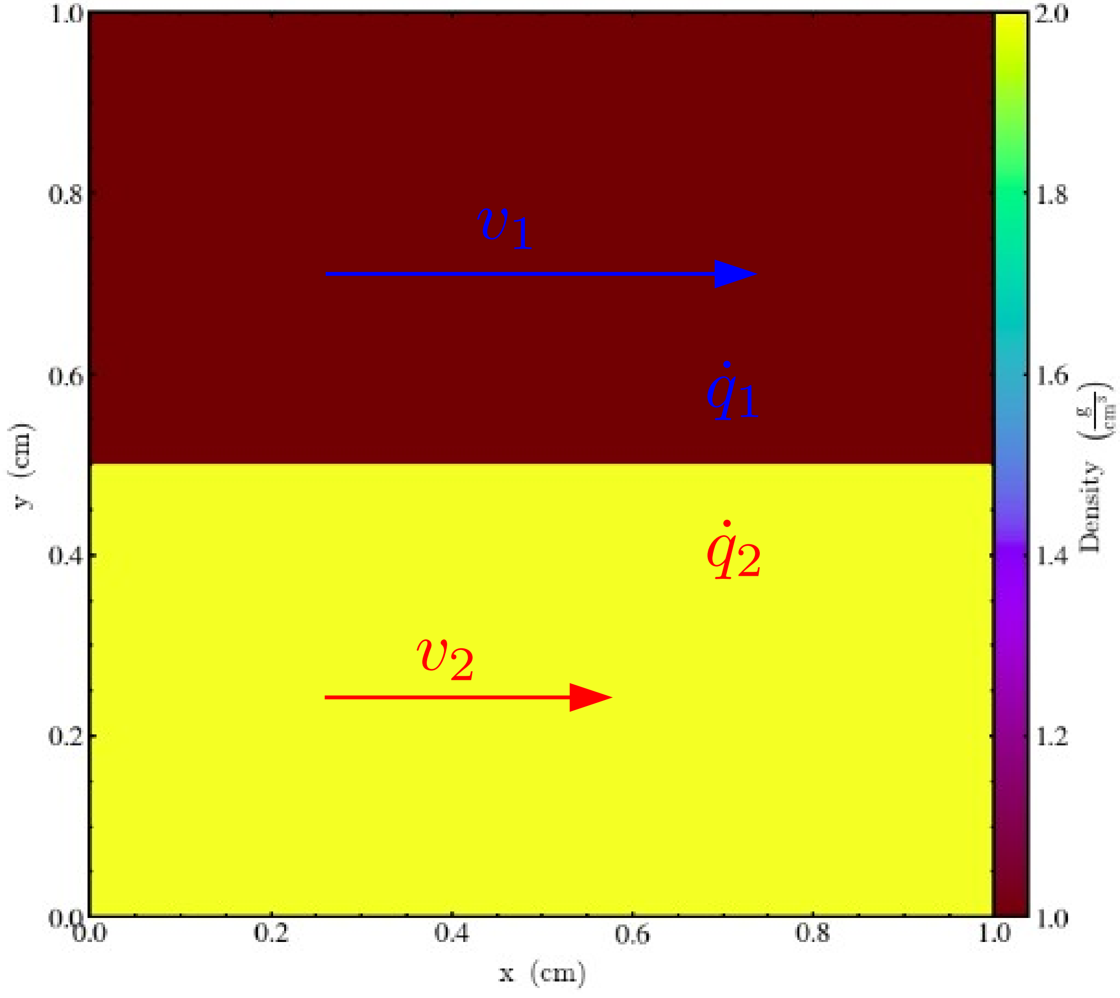
Project A: Mixing in neutron star merger ejecta

Toy model (I): 2D simulation of two fluids moving in positive x-direction with different velocities



Project A: Mixing in neutron star merger ejecta

Toy model (II): 2D simulation of two fluids moving in positive x-direction with different velocities, plus different heating rates



Project A: Mixing in neutron star merger ejecta

Things that you may explore:

– different velocities v_1 and v_2

– different heating rates $\dot{q}_1$ and $\dot{q}_2$

– different initial densities or temperatures

– inhomogeneous or time-dependent heating rate

– any set-up beyond two fluids!

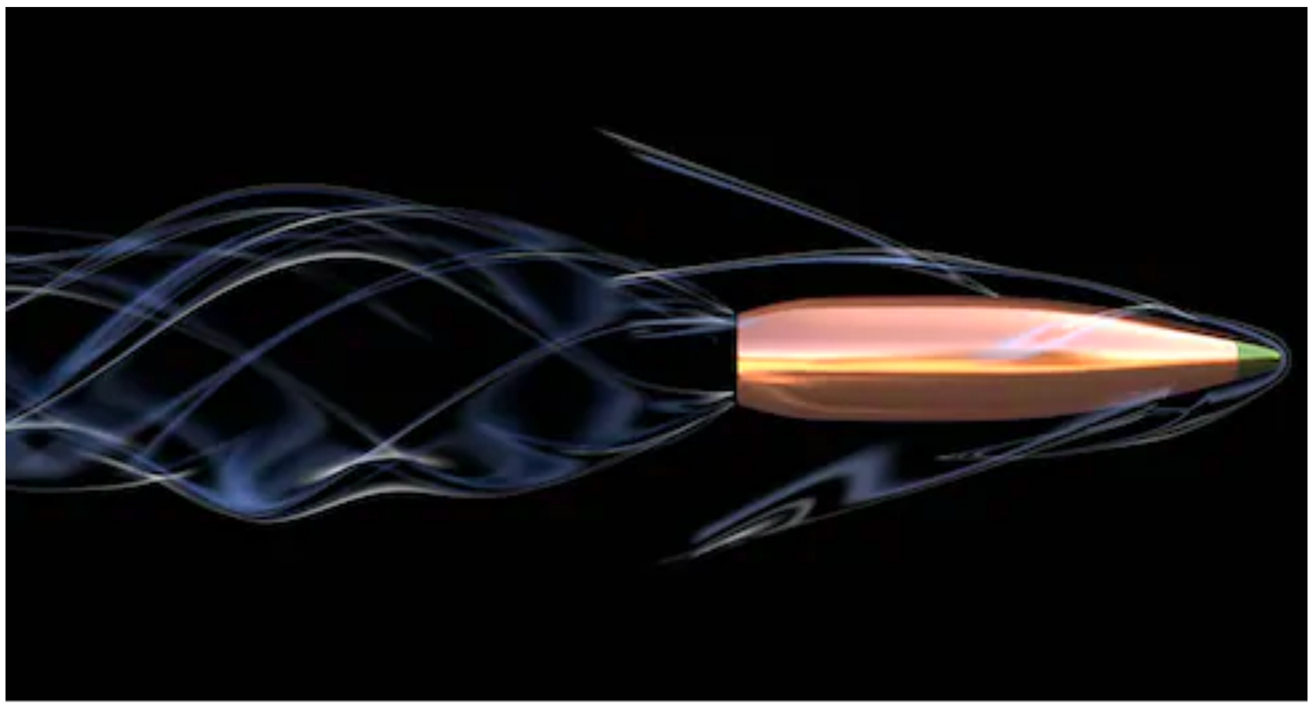
Project B

Project B: Shock Cloud Interaction

Interaction between shock and material is one of the most common astrophysical phenomena.

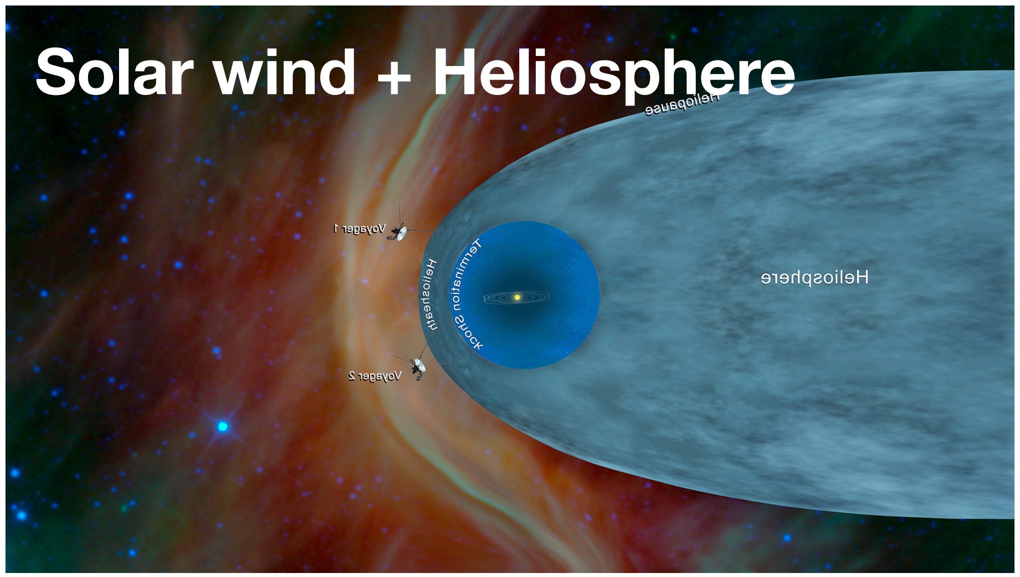
Shock: SN shock, outflow, jet, winds, …etc.
Cloud: Star, ISM, IGM

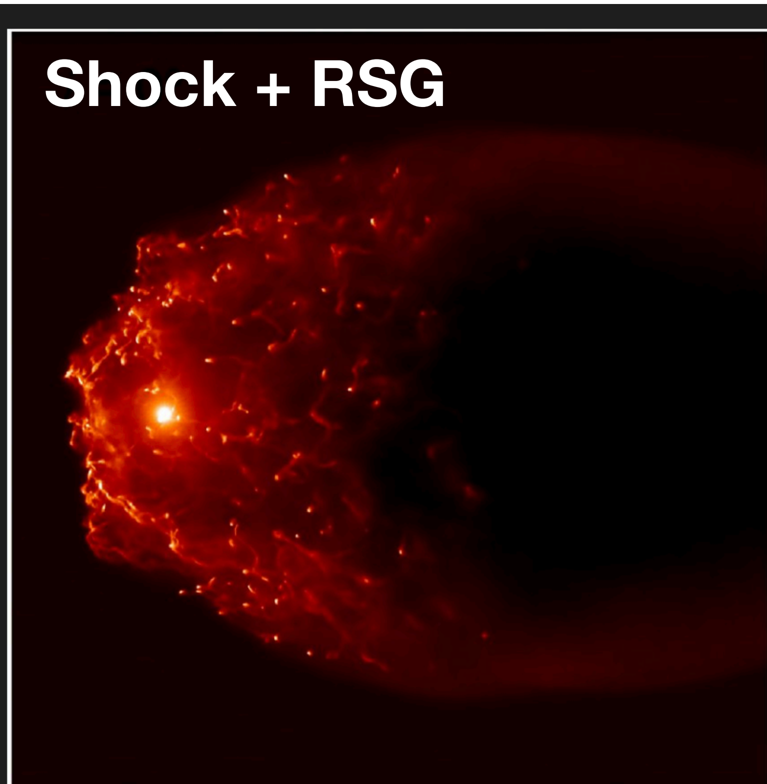
Project B: Shock Cloud Interaction



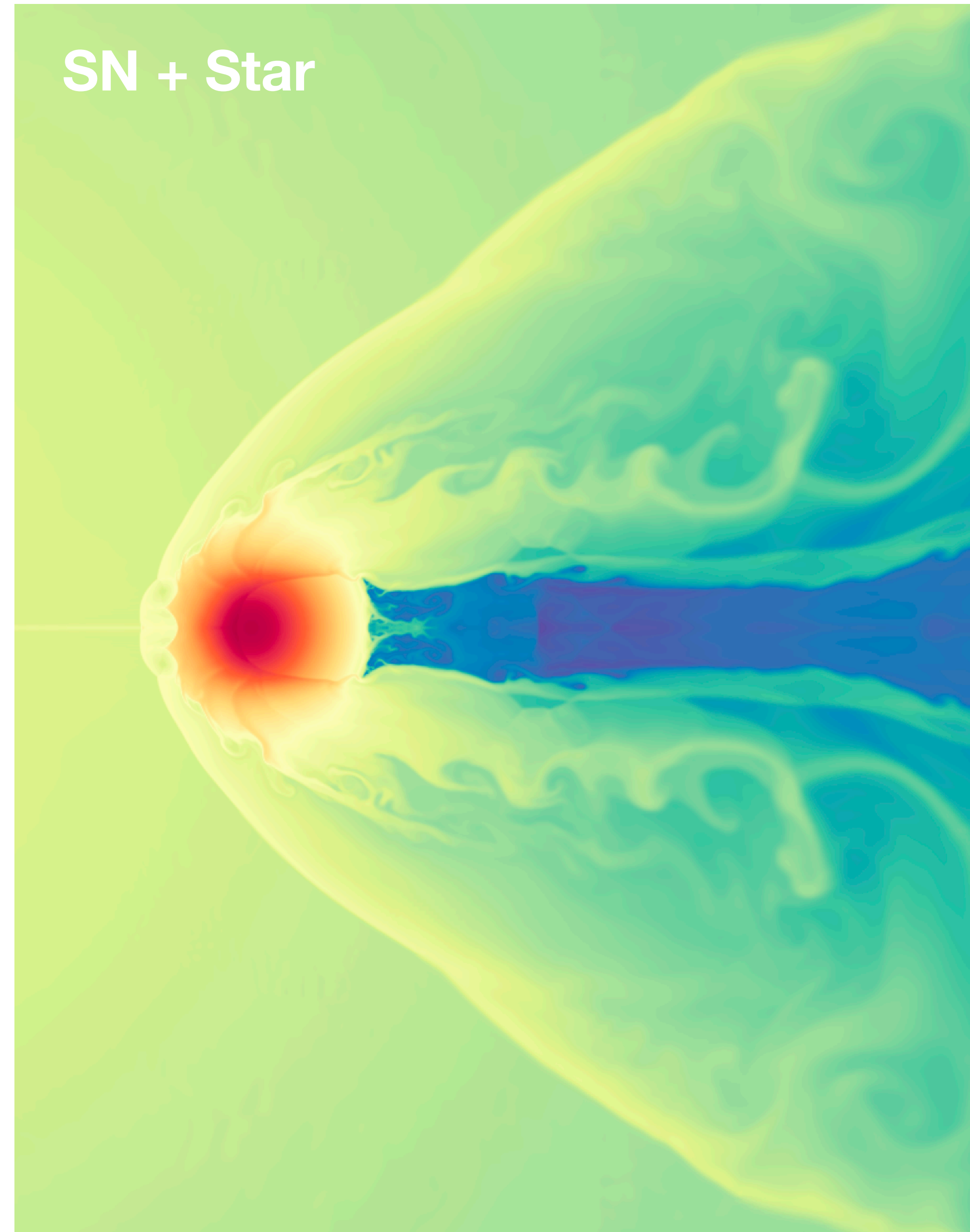
shutterstock.com • 578226307

Project B: Shock Cloud Interaction





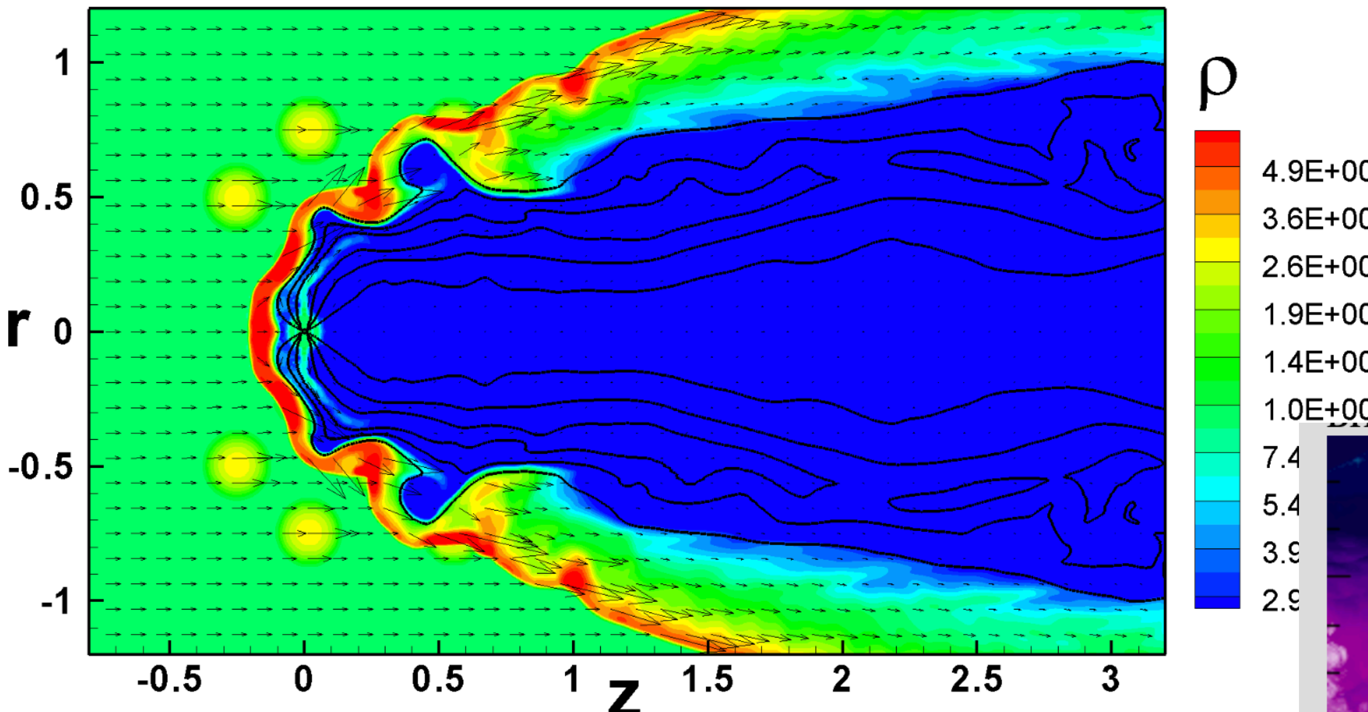
Simulations of the bow shock around the red supergiant star Betelgeuse (Mohamed et al. 2012), used as a cover image by Astronomy & Astrophysics.



NATIONAL TSING HUA UNIVERSITY NCTS PRPC PHYSICS RESEARCH PROMOTION CENTER

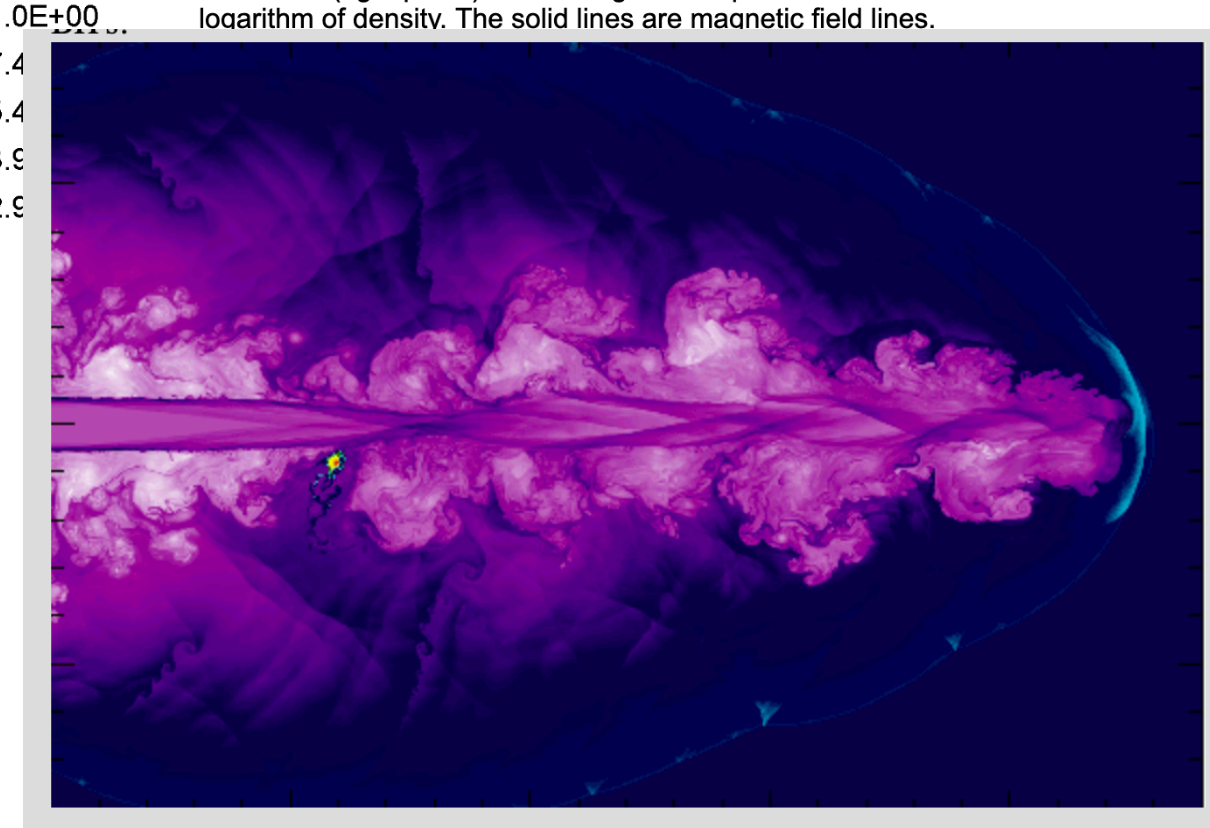
Project B: Shock Cloud Interaction

Modelling the bow shock Pulsar Wind Nebulae propagating through a non-uniform ISM - Toropina, O.D. *et al.* Mon.Not.Roy.Astron.Soc. 484 (2019) no.2, 1475-1486 arXiv:1803.06240 [astro-ph.HE]



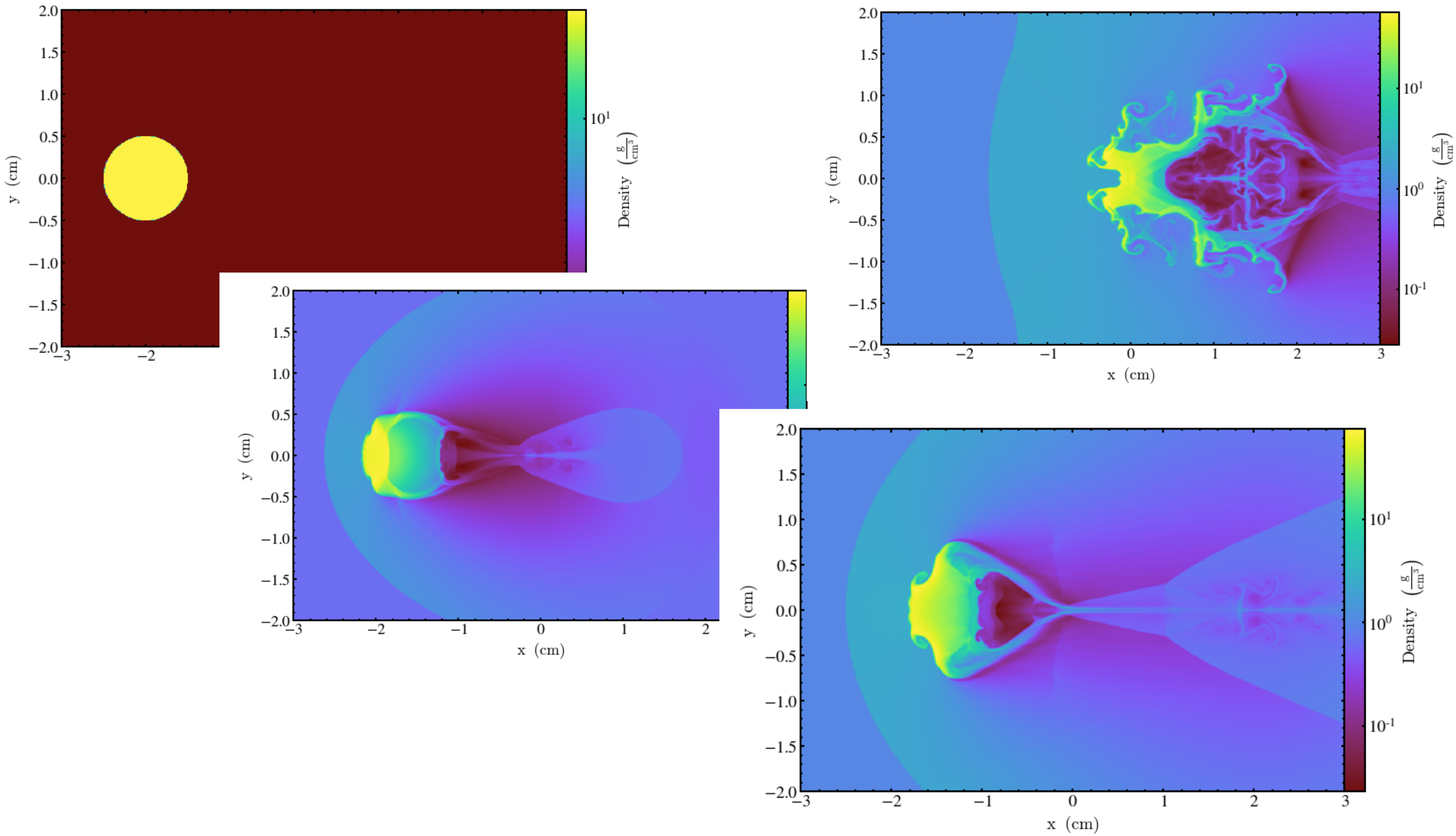
Pular wind + ISM

Interaction of the bow shock with small-scale clouds of maximum density $\rho_{\mathrm{cloud}} = 3\rho_0$ in the model $B1M20w50$ with low σ (left panel) and in the model $B5M20w50$ with medium σ (right panel). The background represents the logarithm of density. The solid lines are magnetic field lines.



Jet + IGM

Project B: Shock Cloud Interaction

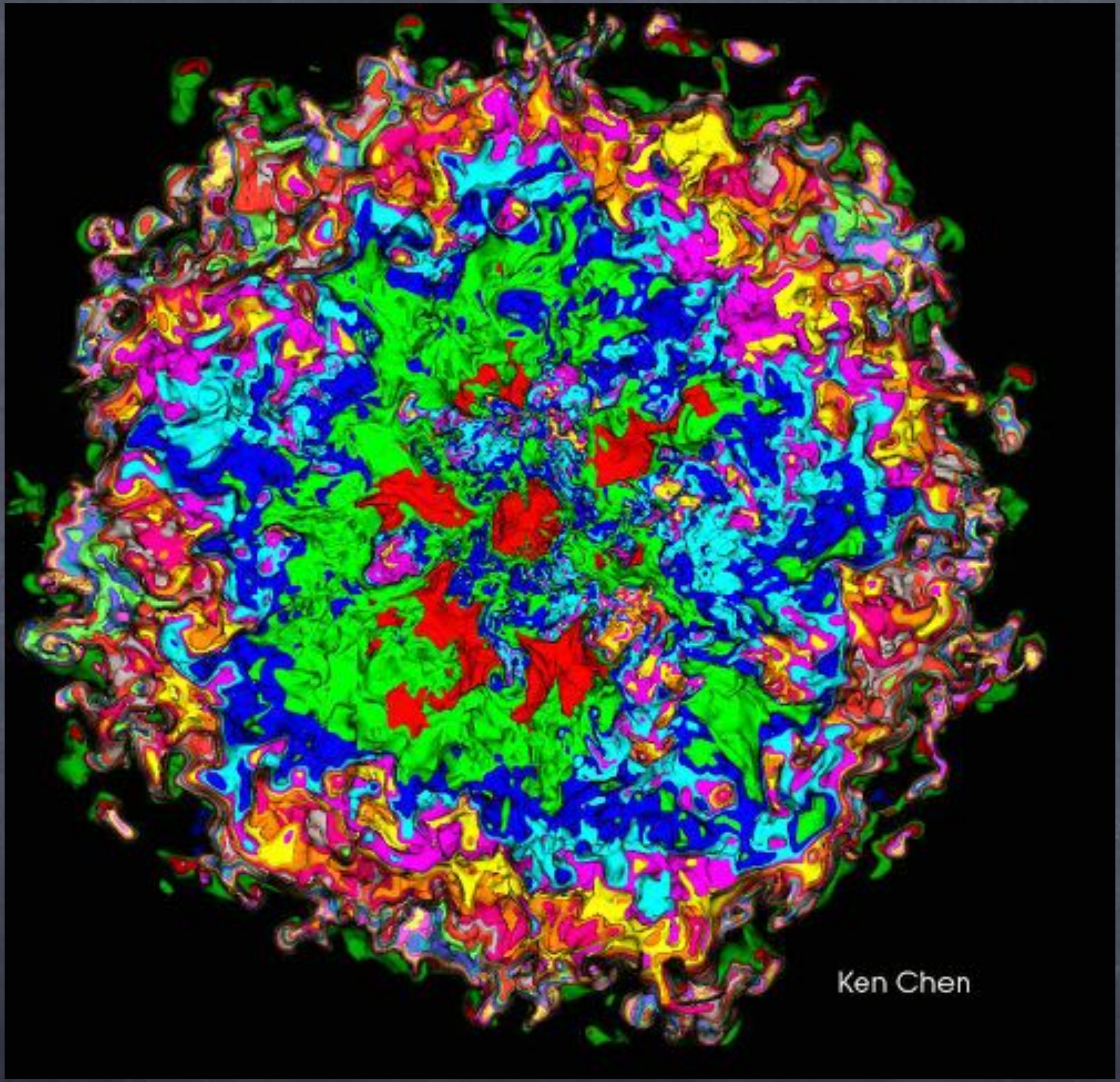


Project B: Shock Cloud Interaction

Things that you may explore:

- Different initial density distribution
- Explore different inflow speed
- Explore different geometry
- Time/Location dependent inflow
- Radiative cooling

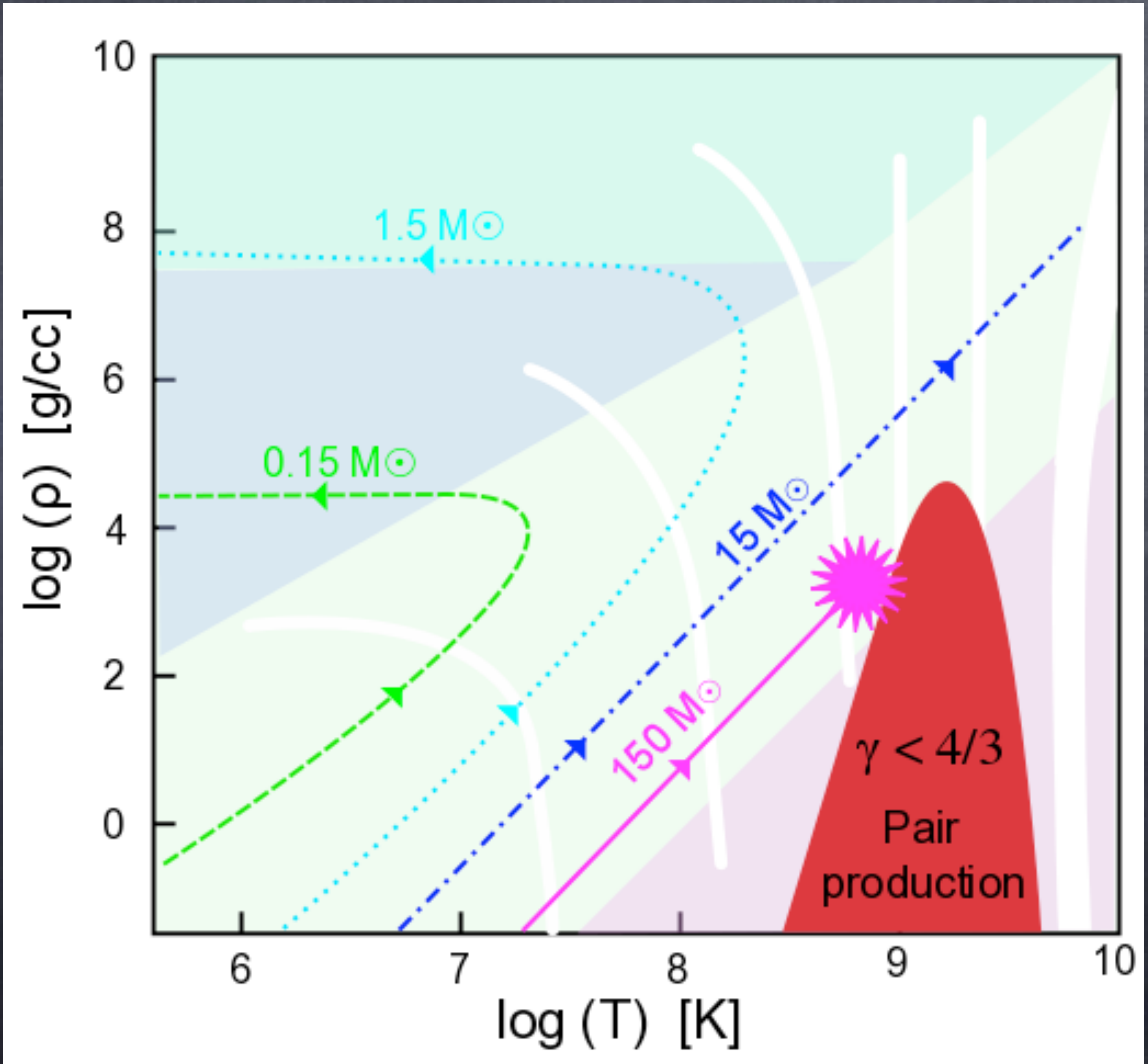
Explode a star in computer



Ke-Jung (Ken) Chen
陳科榮
ASIAA
AFD School, NTHU, 09/05/2019

Stars are atoms of Cosmos

Temperature-Density Diagram of Stellar Evolution



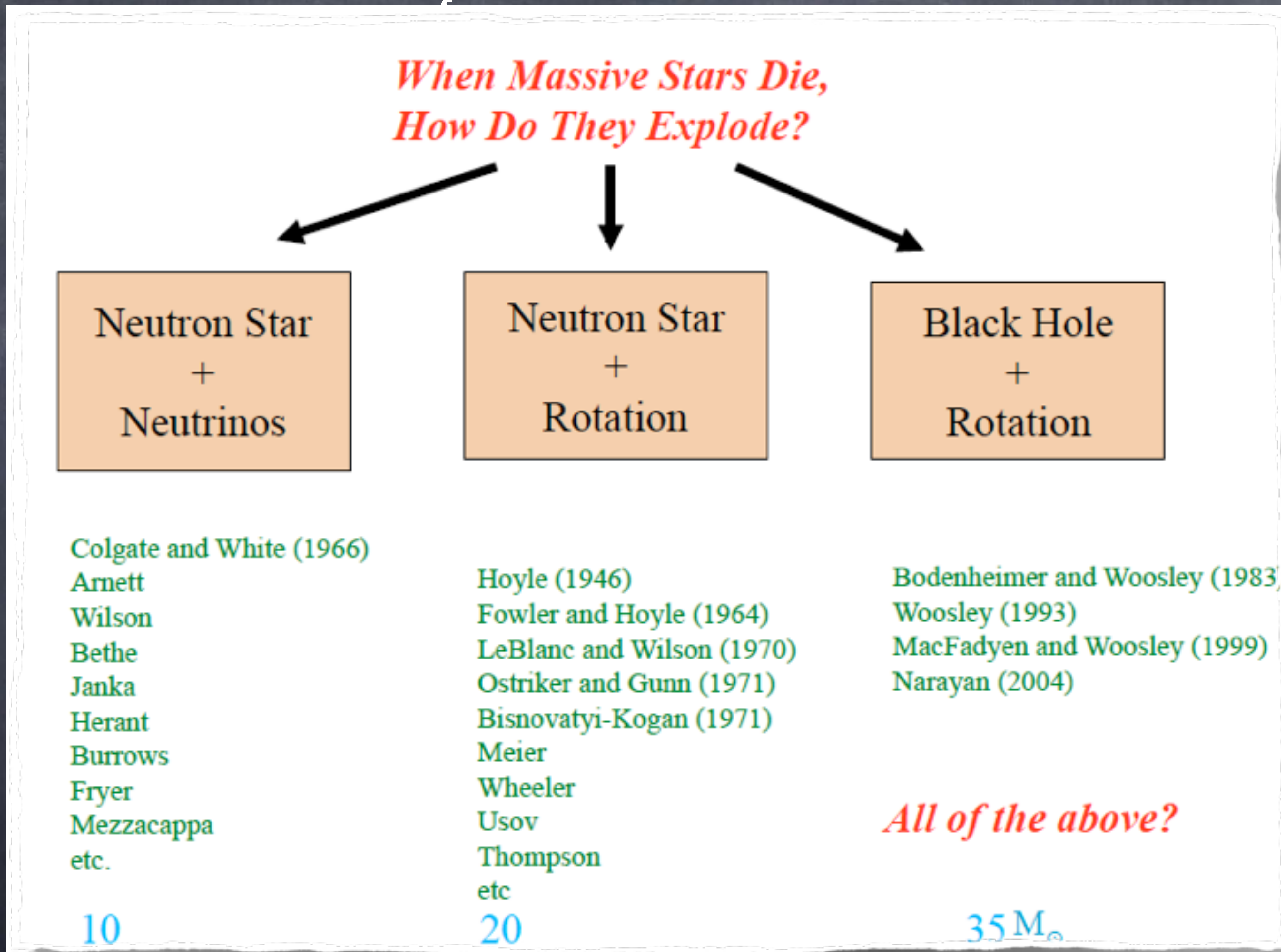
Life of Massive Stars

Advanced Nuclear Burning Stages
(e.g., 20 solar masses)

Fuel	Main Product	Secondary Products	Temp (10^9 K)	Time (yr)
H	He	^{14}N	0.02	10^7
He	C,O	^{18}O, ^{22}Ne s- process	0.2	10^6
C	Ne, Mg	Na	0.8	10^3
Ne	O, Mg	Al, P	1.5	3
O	Si, S	Cl, Ar K, Ca	2.0	0.8
Si	Fe	Ti, V, Cr Mn, Co, Ni	3.5	1 week

Woosley & Heger

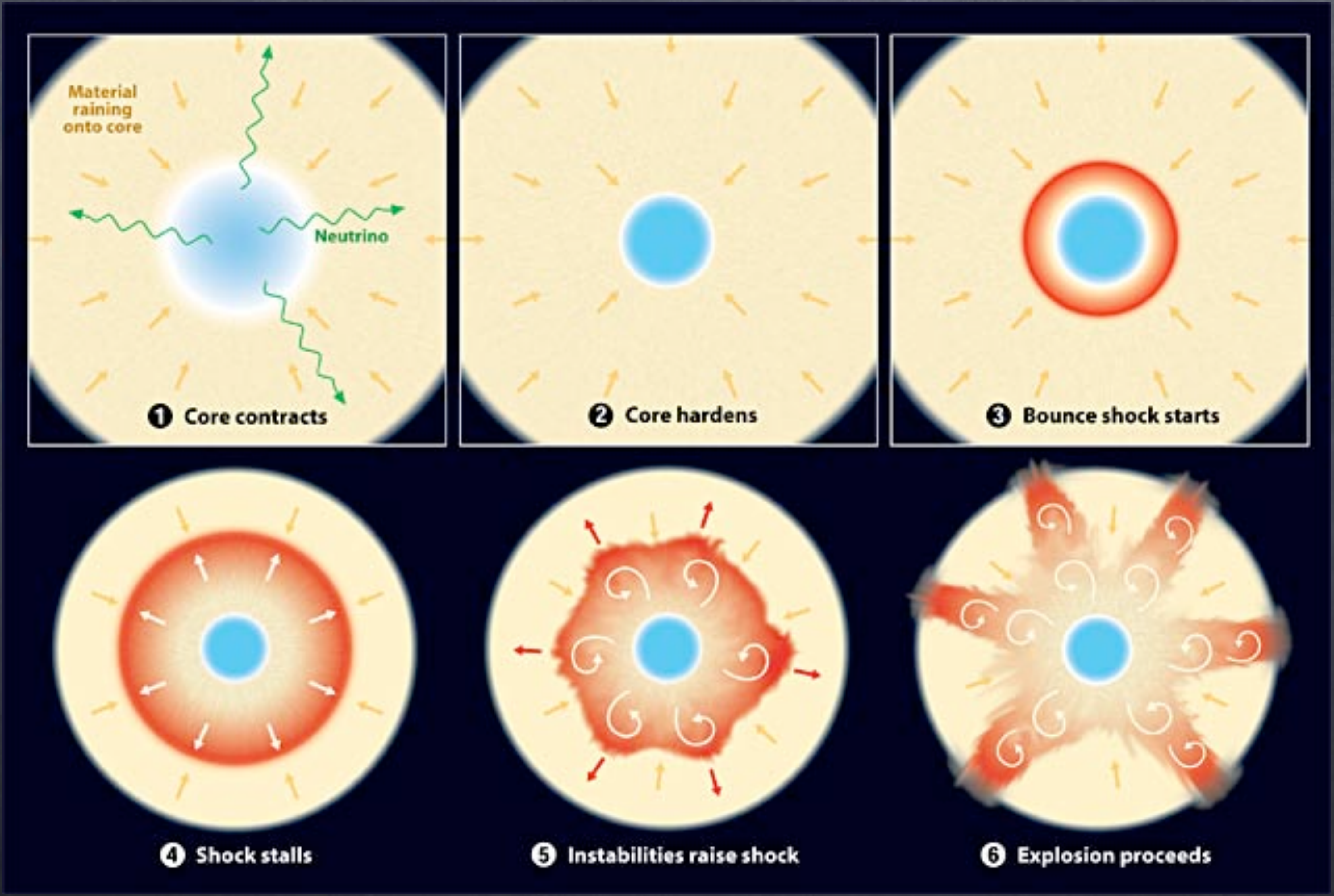
Death of Massive Stars



Woosley

Core-Collapse Supernova

(20 M⊙ > M* > 10 M⊙, E~1E51 erg)



Energy Source

Neutrino Burst Properties:

$$E_{tot} \sim \frac{3}{5}\frac{GM^2}{R}$$

$\sim 3\times10^{53}$ erg

$M = 1.5\, M_{\odot}$

$R = 10$ km

emitted roughly equally in ν_e, $\bar{\nu}_e$, ν_μ, $\bar{\nu}_\mu$, ν_τ, and $\bar{\nu}_\tau$

Time scale

$$\tau_{Diff} \sim \left(\frac{R^2}{l\ c}\right) \qquad l = \frac{1}{\kappa_\nu \rho}$$

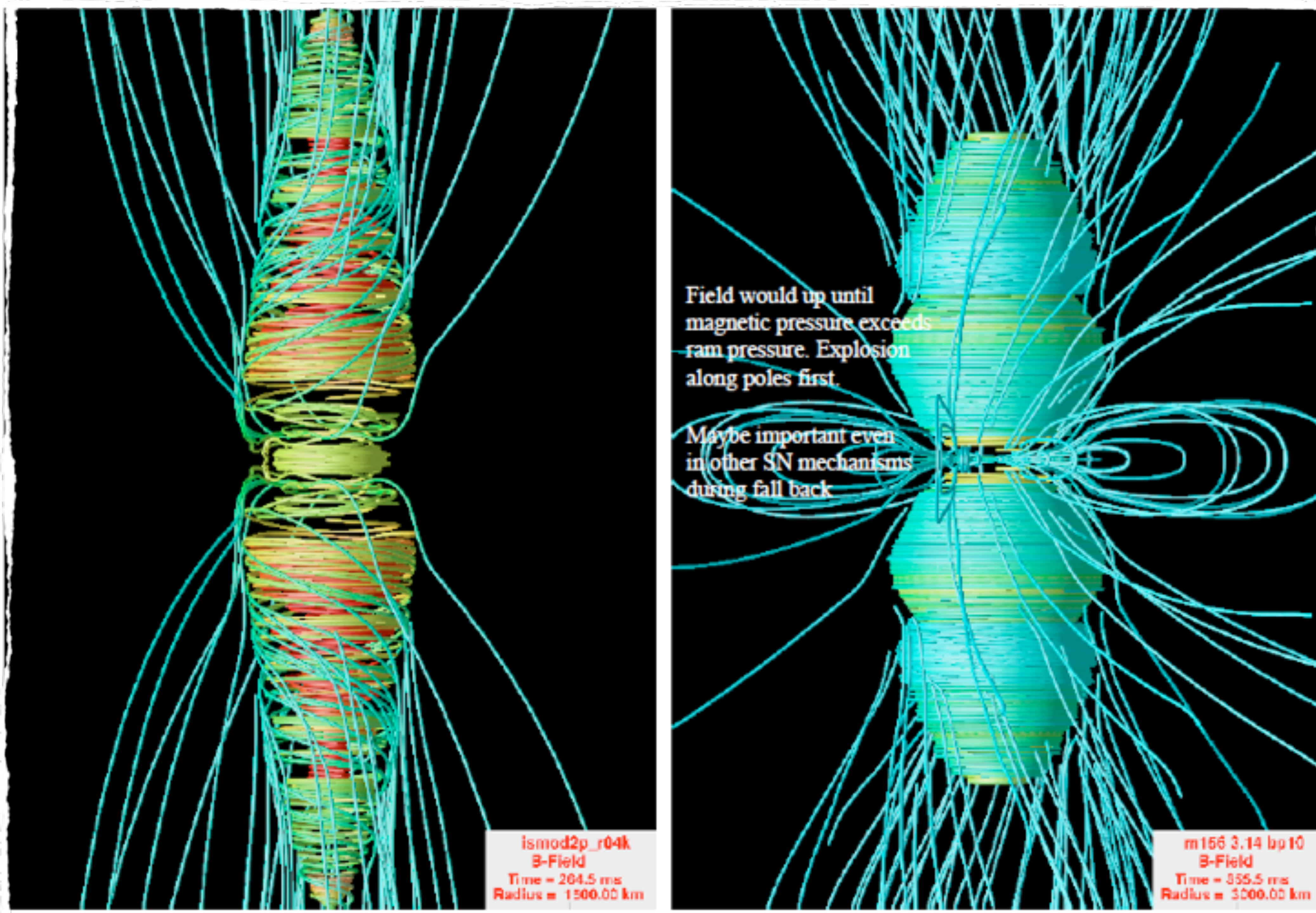
$\kappa_\nu \sim 10^{-16}\ \text{cm}^2\ \text{gm}^{-1}$ for $\varepsilon_\nu =$ 50 MeV (next page)

$\rho \sim 3\times10^{14}\ \text{gm cm}^{-3} \quad \Rightarrow \quad l \sim$ 30 cm $\qquad R \sim 20$ km

$$\tau_{Diff} \sim \left(\frac{(2\times10^6)^2}{30 \cdot 3\times10^{10}}\right) \sim 5\ \text{sec}$$

Very approximate

Hypernovae
(E > 1E52 erg)



Burrows et al 2007, *ApJ*, **664**, 416

Energy Sources

Assuming the emission of high amplitude ultra-relativistic MHD waves, one has a radiated power

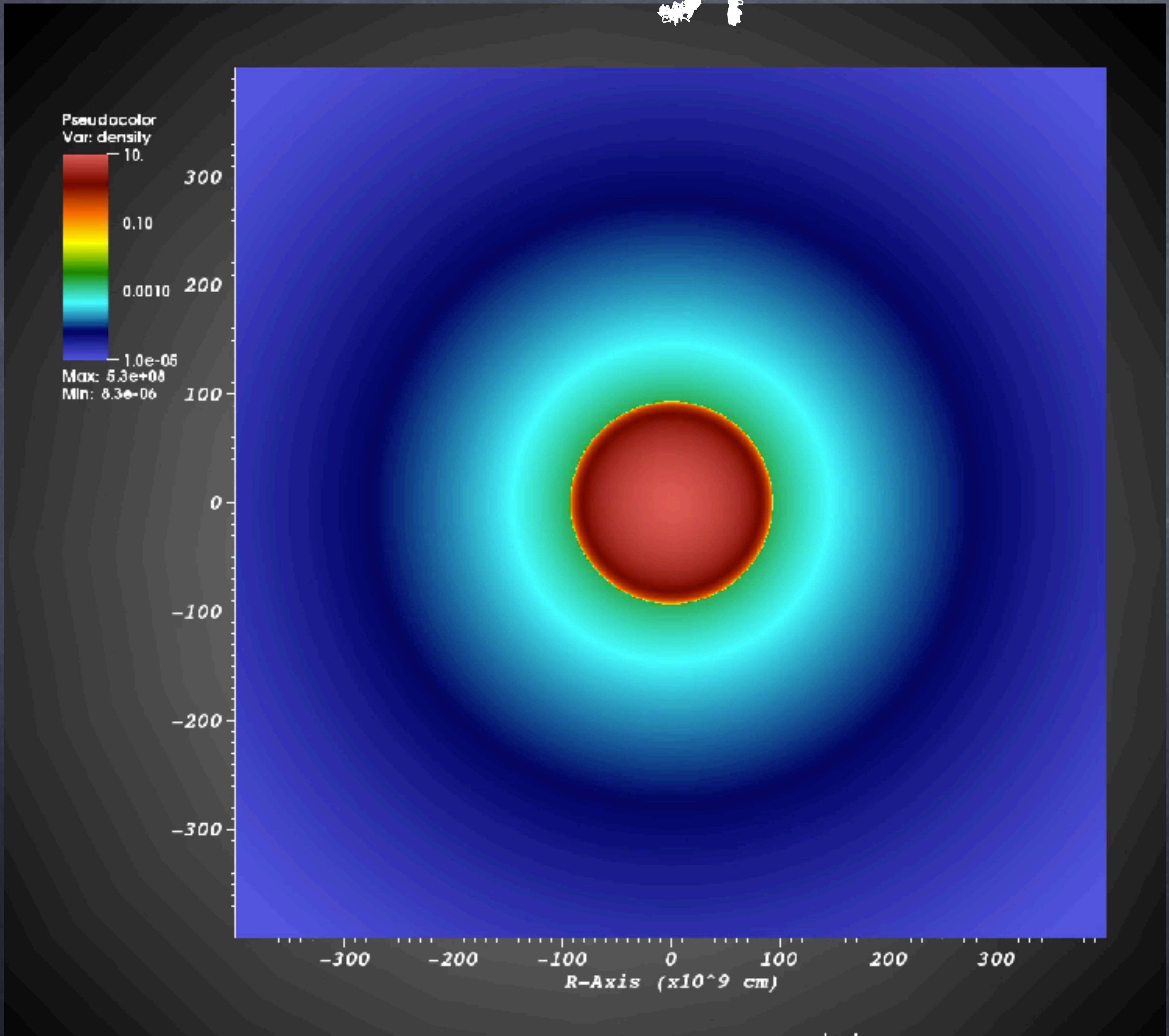
$$P \sim 6 \text{ x } 10^{49} \ (1 \text{ ms/P})^4 \, (B/10^{15} \text{ gauss})^2 \text{ erg s}^{-1}$$

and a total rotational kinetic energy

$$E_{rot} \sim 4 \ x \ 10^{52} \, (1 \text{ ms/P})^2 \ (10 \text{ km/R})^2 \text{ erg}$$

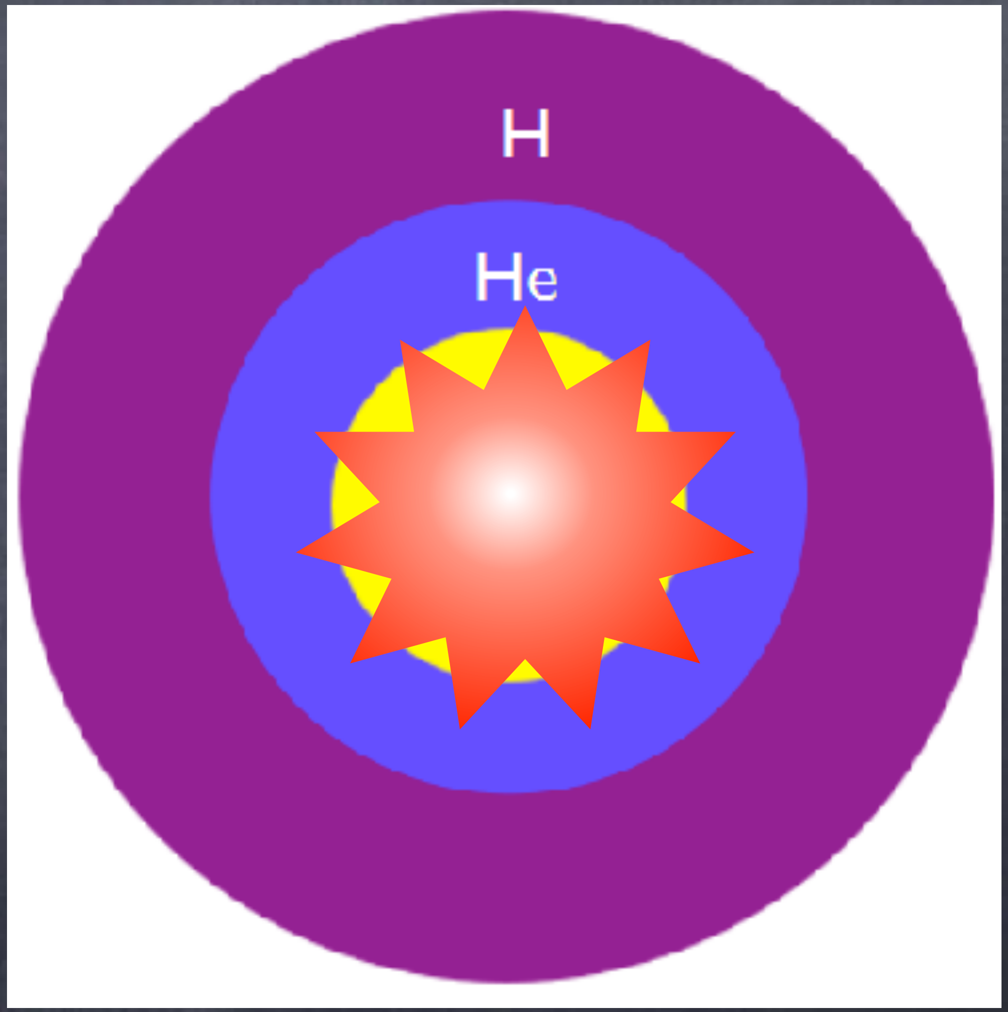
For magnetic fields to matter one thus needs magnetar-like magnetic fields and rotation periods (for the cold neutron star) of < 5 ms. This is inconsistent with what is seen in common pulsars. Where did the energy go?

GRB and Hypernova



Project C
Blowing up a star with Flash

- Explosion Energy E~1e50- 1e52 erg?
- Size and shape of the energy deposition area?
- Properties of surrounding ISM and its density/temperature/... profile?
- Striped Envelope SNe?



Have fun in blowing up Stars

国立清華大學 NATIONAL TSING HUA UNIVERSITY NCTS PRPC PHYSICS RESEARCH PROMOTION CENTER

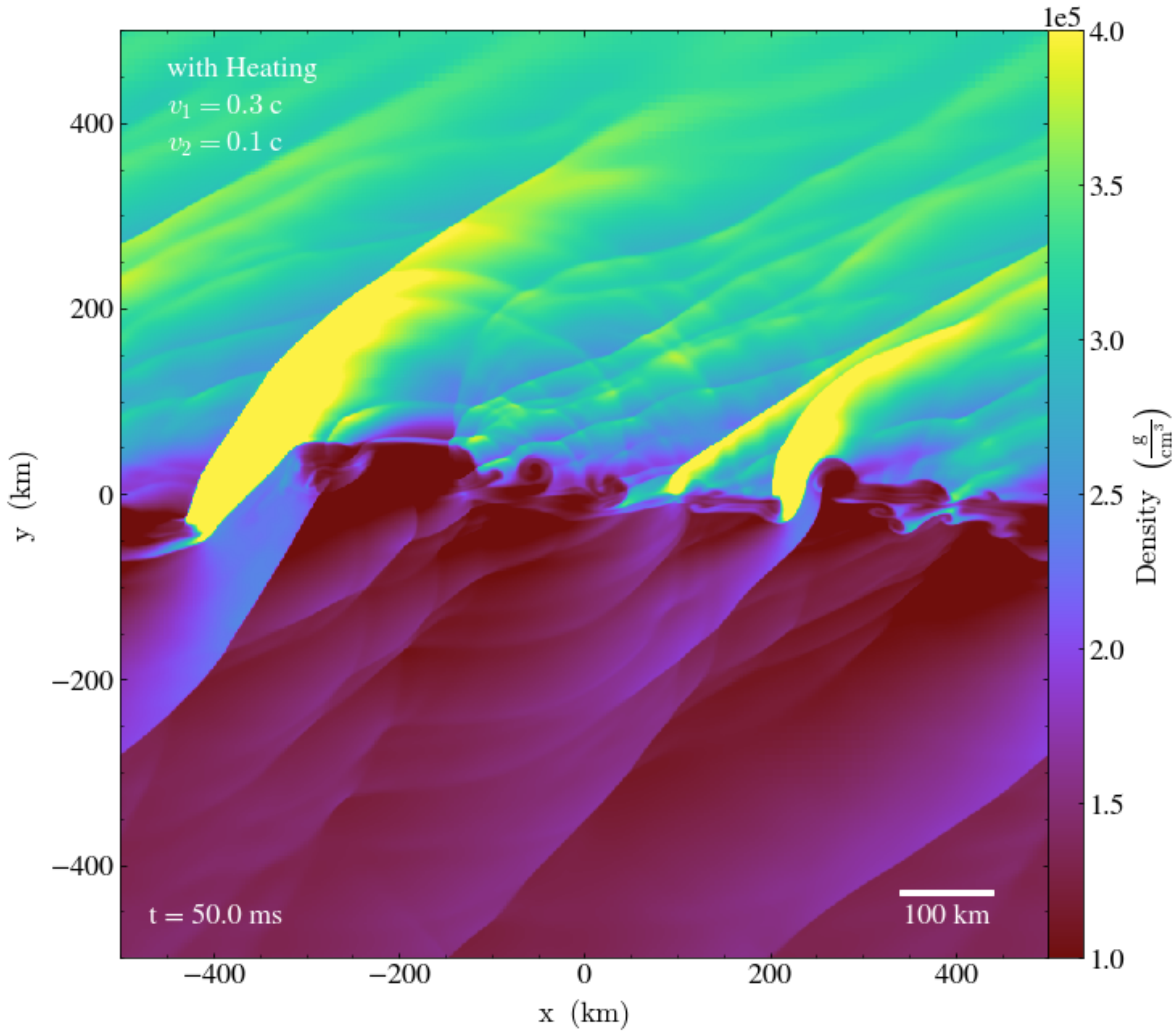
Project A

- ./setup LocalKilonova -2d -auto -maxblocks=4000

REQUIRES Driver
REQUIRES physics/Hydro
REQUIRES physics/Eos
REQUIRES physics/Eos/EosMain/Helmholtz
REQUIRES Simulation/SimulationComposition/LocalKilonova
REQUIRES physics/sourceTerms/Heat/HeatMain/LocalKilonova

flash4, flash.par, SpeciesList.txt, helm_table.dat

Project A



with Heating
$v_1 = 0.3$ c
$v_2 = 0.1$ c
t = 50.0 ms
100 km
y (km)
x (km)
400
200
0
−200
−400
1e5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
Density $\left(\frac{g}{cm^3}\right)$

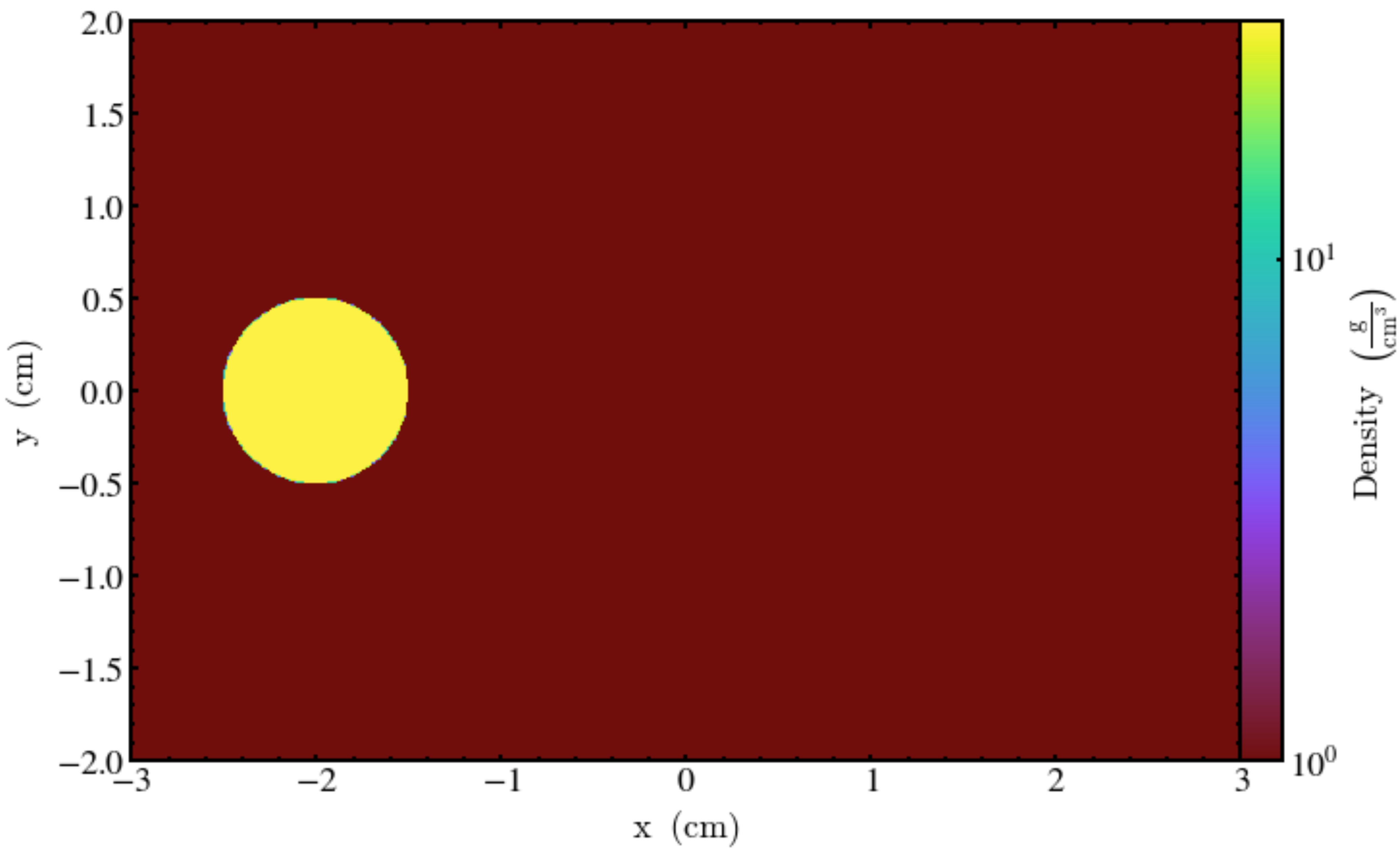
Project B

- ./setup SchoolProject2 -2d -nxb=16 -nyb=16 -auto -maxblocks=4000

REQUIRES Driver
REQUIRES physics/Hydro
REQUIRES physics/Eos
REQUIRES Grid/GridBoundaryConditions/OneRow

flash4, flash.par

Project B



2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
y (cm)
−3
−2
−1
0
1
2
3
x (cm)
10^1
10^0
Density $\left(\frac{g}{cm^3}\right)$

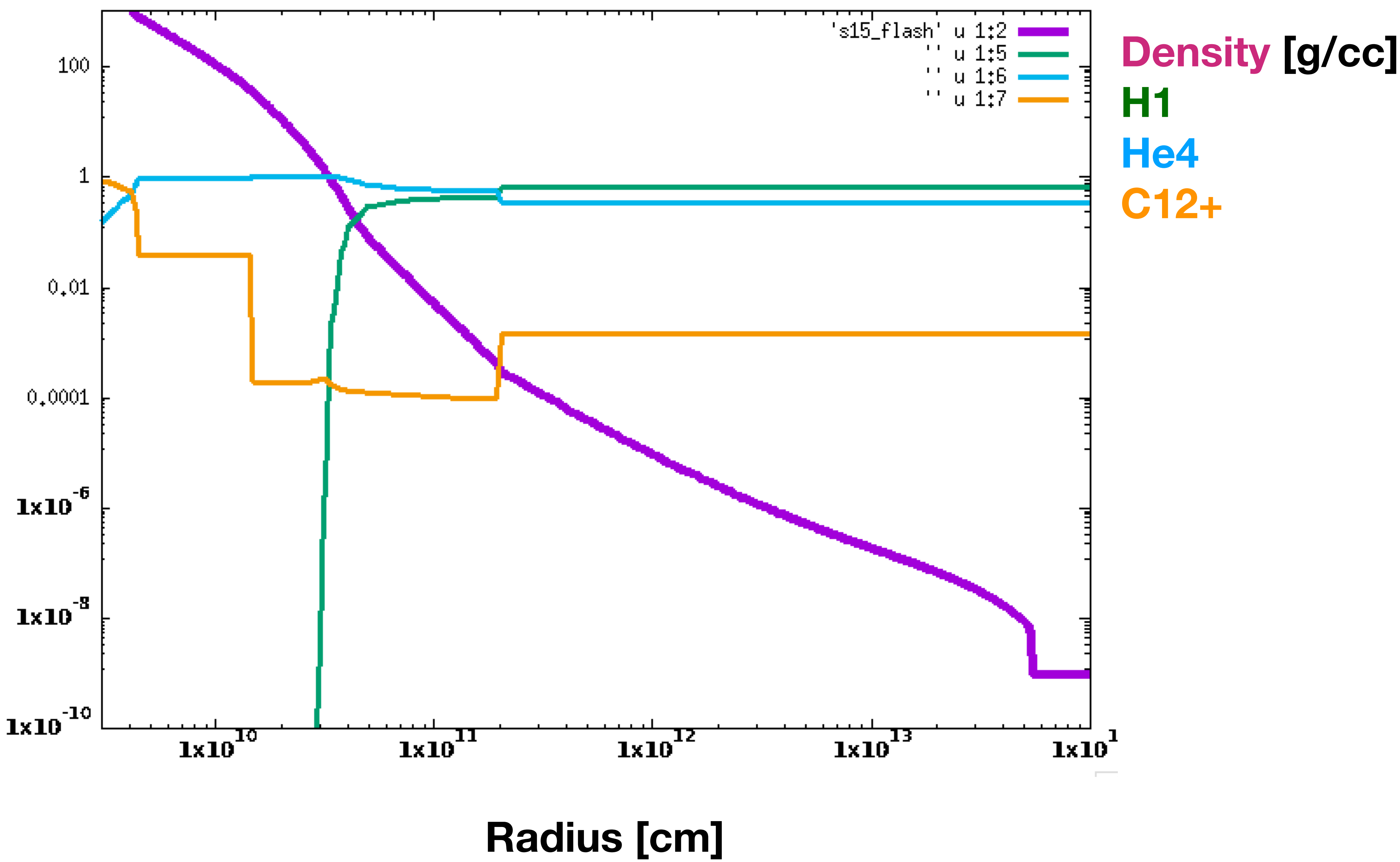
Project C

- ./setup ThermoBomb -2d +cylindrical -maxblocks=4000 -nxb=8 -nyb=8 -auto -objdir bomb +newMpole

REQUIRES Driver
REQUIRES PhysicalConstants/PhysicalConstantsMain
REQUIRES physics/Hydro
REQUIRES physics/Eos/EosMain/Helmholtz
REQUIRES IO/IOMain
REQUIRES Simulation/SimulationComposition/H-He-C

flash4, flash.par, s15_flash, SpeciesList.txt, helm_table.dat

Project C


's15_flash' u 1:2
'' u 1:5
'' u 1:6
'' u 1:7
100
1
0.01
0.0001
1x10^-6
1x10^-8
1x10^-10
1x10^10
1x10^11
1x10^12
1x10^13
1x10^1
Density [g/cc]
H1
He4
C12+
Radius [cm]

Project C